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Building a Bridge between Inundated Shores: Analyses on integrated Disaster Risk Reduction and Climate Change Adaptation Policies and Measures

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ACADEMIC DISSERTATION in Environmental Economics

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Title Building a Bridge between Inundated Shores: Analyses on Integrated Disaster Risk Management and Climate Change Adaptation Policies and Measures

Abstract

This thesis consists of an introduction and four articles which analyse disaster risk management (DRM), including disaster risk reduction (DRR), disaster management and climate change adaptation (CCA) from economic and policy perspectives. The main research question is: what are the means to overcome the salient challenges in DRM and CCA policies and measures which have been designed to reduce the risks posed by extreme weather under uncertainty? Theoretically, it advances the policy level development of DRM and CCA integration and provides a mathematical definition for over-adaptation to climate change. Empirically, it analyses integrated DRM and CCA policies and measures, and analyses challenges related to their development and implementation.

Article I provides a formal definition for DRR and CCA policy integration at horizontal (inter-ministerial) and vertical (intra-ministerial) dimensions to assess DRR and CCA policy-making and analyses policies and their integration challenges in Zambia. The theoretical contribution to the literature is the formal definition for DRR and CCA policy integration and the empirical contribution is provided by evidence of potential challenges created by the governance system.

Article II discusses the contribution of the underlying vulnerability drivers of governance, societal and political factors, culture, policies and their implementation, and argues that vulnerability reduction is a key aspect in reducing disaster and climate change risk. The theoretical contribution furthers the discussion on new dimensions in climate change risk analyses by emphasising the potential impacts of societal development, such as social trends and social cohesion, in effective DRM and CCA. The article contributes to the empirical literature by assessing Nordic welfare state structures as a means to reduce disaster risk and climate change.

Article III analyses the costs and benefits of a major integrated DRM and CCA policy in Finland, and describes how over-adaptation, i.e. over-investment in DRM and CCA may affect the legitimacy of a policy aiming partially at reducing extreme weather risk. The article contributes to the theoretical literature by providing a mathematical definition for over-adaptation and to the empirical literature through the case study.

Article IV assesses the effects of a potential innovation in weather service provision to improve CCA and safety in the road transport sector. The article identifies and describes the main trends and potential innovations in the provision and use of weather services. It contributes to the empirical literature on CCA and weather service benefit valuation.

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Nimeke	Sillan rakentaminen kahden tulvineen rannan välille: Analyysejä integroitujen katastrofiriskien hallinnan ja ilmastonmuutokseen sopeutumisen politiikoista ja toimista

Tiivistelmä

Tämä tutkielma koostuu johdannosta ja neljästä artikkelista, joissa analysoidaan sekä katastrofiriskien hallintaa (Disaster Risk Management – DRM) että ilmastonmuutokseen sopeutumista (Climate Change Adaptation – CCA) taloustieteellisestä ja politiikka-analyysin näkökulmasta. Katastrofiriskien hallintaan sisältyvät katastrofiriskien vähentäminen (Disaster Risk Reduction – DRR) ja katastrofien hallinta (Disaster Management). DRM- ja CCA-politiikkojen tarkoituksena on vähentää äärimmäisten sääilmiöiden aiheuttamia riskejä ottaen huomioon ilmastonmuutoksen mukanaan tuoma epävarmuus. Tutkielman pääkysymys on: millä keinoin voidaan ratkaista DRM- ja CCA-politiikkoihin ja -toimiin liittyviä merkittäviä haasteita? Teoreettisesti tutkielma edistää DRM:n ja CCA:n politiikka-analyysia sekä esittää matemaattisen määritelmän ilmastomuutoksen liialliseen sopeutumiseen. Empiirisesti työssä analysoidaan integroituja DRM- ja CCA-politiikkoja ja- toimia sekä analysoidaan niiden kehittämiseen ja toteuttamiseen liittyviä haasteita.

Artikkelissa I kehitetään DRR- ja CCA-politiikkojen integroinnin muodollinen määritelmä horisontaalisessa (ministeriöiden sisäisessä) ja vertikaalisessa (ministeriöiden välisessä) ulottuvuudessa. Empiirinen osuus analysoi Sambian tilannetta ja haasteita. Teoreettinen panos kirjallisuuteen on muodollinen määritelmä DRR- ja CCA-politiikkaintegroinnille ja empiirinen panos tulee arvioista hallinnon tilanteen aiheuttamista mahdollisista haasteista.

Artikkelissa II käsitellään katastrofiriskien taustalla olevien haavoittuvuustekijöiden, kuten yhteiskunnallisten ja poliittisten tekijöiden, kulttuurin, politiikan ja niiden täytäntöönpanon vaikutusta riskien vähentämisessä. Artikkelin teoreettinen panos edistää keskustelua ilmastoriskianalyysien uusista ulottuvuuksista korostamalla yhteiskunnallisen kehityksen, kuten sosiaalisten suuntausten ja yhteenkuuluvuuden, mahdollisia vaikutuksia tehokkaassa DRM:ssä ja CCA:ssa. Artikkeli tukee empiiristä kirjallisuutta arvioimalla pohjoismaisen hyvinvointivaltion rakenteita keinona vähentää katastrofi- ja ilmastonmuutosriskiä.

Artikkelissa III analysoidaan integroidun DRM- ja CCA- politiikan kustannuksia ja hyötyjä Suomessa: Lisäksi kuvataan, kuinka liiallinen panostaminen katastrofiriskien hallintaan ja sopeutumiseen voi vaikuttaa politiikan hyväksyttävyyteen. Artikkelin teoreettinen panos tulee matemaattisen määritelmän esittämisestä liialliseen CCA:han, ja empiirinen panos tulee tapaustutkimuksen kautta.

Artikkelissa IV arvioidaan, miten innovaatiot voivat vähentää sään ääri-ilmiöiden ja ilmastonmuutoksen aiheuttamia haitallisia vaikutuksia tieliikennesektorilla. Artikkelissa tunnistetaan ja kuvataan sääpalvelujen tarjoamisen ja käytön tärkeimmät suuntaukset ja mahdolliset innovaatiot, sekä arvioidaan millaisia taloudellisia hyötyjä tieliikenteen turvallisuuden parantaminen tuo. Artikkeli on osa empiiristä CCA-kirjallisuutta ja tarjoaa esimerkin sääpalvelujen taloudellisten hyötyjen arvioinnista.

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I am writing this the night before this thesis goes to print. I started believing that this moment would only ever come a few months ago. This thesis has felt like a never-ending journey, which started in the Autumn 2008, almost 12 years ago; a time before smartphones and when Nokia was one of the largest mobile phone companies. The journey has been full of trials and tribulations, amazing experiences, a lot of tears and a burn out. Along the way, there have been a lot of people I have wanted to thank for either providing me professional support, personal support, and in the best case, both.

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This thesis consists of two parts; the introduction and the articles. Thanks to my co-authors, the articles were the relatively easy part. Two of the articles were written in close collaboration with Väinö Nurmi. Väinö, of my colleagues you deserve my biggest gratitude. I have learnt so much from you over the years; your knowledge, skills and attitude are something I truly admire. Senja Väätäinen-Chimpuku, you had a tremendous impact on my career. Our joint article was an extremely smooth process, got me interested in disasters and eventually shaped this entire thesis. Atte Harjanne and Riina Haavisto, not only were we close colleagues for many years, facilitating workshops and writing reports, but we even managed to write a joint paper, for which I am very grateful.

The introduction was the hard part. For that, for the entire thesis and for the fact that I am still relatively sane after all this, my biggest, heartfelt thanks go to Dave, my husband. Dave, without you I would have given up years ago. You got me out of bed when I was struggling to go to work, you calmed me down from my panic attacks, you wiped my tears that I had too often, and you drank beer with me when that was what I needed the most. You also gave professional comments, helped me to formulate my research questions and conclusions, and patiently proof-read my articles and this thesis.

There are also a lot of former FMI colleagues and friends I want to thank for various reasons. From FMI, Athanasios Votsis, Reija Ruuhela, Sanna Luhtala, Otto Hyvärinen, Mikko Laapas, Tiina Ervasti, Juha A. Karhu and all other colleagues from my old group and unit deserve a big thanks. Also, many other people from FMI, whom I consider more my friends than colleagues, deserve acknowledgments: Alexey, Andreas, Curtis, Edith, Iolanda, Markus, Stelios, Svante, Timo, Toni and Ulpu. Thanks for the lunch and coffee breaks and beers that kept me going.

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My sincere gratitude goes to the Maj and Tor Nessling Foundation who funded the first three years of my PhD studies. I also want to thank the NORDRESS; Centre of Excellence under the Social Security Programme of NordForsk, for providing me a travel grant to begin writing the thesis' introduction in Copenhagen. Thanks are due to the Copenhagen Center for Disaster Research (COPE) at the University of Copenhagen for providing me an office; Nathan, Silje and Christine for the excellent company in that office and Kristian for the spare laptop you arranged after my own broke just after I arrived. Without the five weeks in Copenhagen, this thesis would have never been written. Thanks are also due to my current employer, the National Audit Office of Finland, who supported the very final steps of my thesis by providing me leave of absence after the pre-examiners granted me the permission to defend.

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My choices throughout my life have resembled more like a piece of driftwood than any conscious choice; my PhD studies and this thesis being a prime example. Nevertheless, my family—my parents Mikko and Elina and brother Matti—you have always supported me and tirelessly asked when I will finish my thesis. Thanks for not giving up.

Helsinki, May 2020

Karoliina Pilli-Sihvola

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LIST OF ORIGINAL PUBLICATIONS

I. Pilli-Sihvola, Karoliina., Väätäinen-Chimpuku, Senja. 2016. Defining climate change adaptation and disaster risk reduction policy integration: Evidence and recommendations from Zambia, *International Journal of Disaster Risk Reduction,* 19, 461-473.

II. Pilli-Sihvola, Karoliina., Harjanne, Atte., Haavisto, Riina. 2018. Adaptation by the least vulnerable: Managing climate and disaster risks in Finland, *International Journal of Disaster Risk Reduction*, 31, 1266-1275

III. Nurmi, Väinö., Pilli-Sihvola, Karoliina., Gregow, Hilppa., Perrels, Adriaan. 2019. Overadaptation to Climate Change? The Case of the 2013 Finnish Electricity Market Act. *Economics of Disasters and Climate Change*, 3, 161-190.

IV. Pilli-Sihvola, Karoliina., Nurmi, Väinö., Perrels, Adriaan., Harjanne, Atte., Bösch, Patrick., Ciari, Francesco. 2016. Innovations in weather services as a crucial building block for climate change adaptation in road transport. *European Journal of Transport and Infrastructure Research*, 16, 150-173.

This thesis consists of four articles. Karoliina Pilli-Sihvola is the lead author in Articles I, II and IV. In all the articles, she has been the main contributor to the theoretical sections on Disaster Risk Reduction and Climate Change Adaptation. In Articles I and II she has been the main contributor to the analysis of the studies, in Article III she came up with the research idea, and in Articles III and IV she has contributed to the economic and uncertainty analysis. She had the main responsibility in writing Articles I and II and shared the main responsibility of writing Articles III and IV.

Article I was written as part of the Academy of Finland FICCA SAFE-MET (no:264058) project. Article II was written was supported by the Nordic Centre of Excellence for Resilience and Societal Security – NORDRESS, which is funded by the Nordic Societal Security Programme. Article III was written as part of an ELASTINEN (Proactive management of weather and climate related risks) project, funded from the Government's 2015 plan for analysis, assessment and research. Article IV was written as part of the ToPDAd (Tool-supported policy development for regional adaptation) project, funded by the European Commission through the 7th Framework Programme for Research.

ABBREVIATIONS

CO_2	Carbon dioxide
CBA	Cost Benefit Analysis
CCA	Climate Change Adaptation
DM	Disaster Management
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
GHG	Greenhouse Gas
IPPC	Intergovernmental Panel on Climate Change
UNDRR	United Nations Office for Disaster Risk Reduction

1 INTRODUCTION

1.1 Hazards, disasters and climate change

As witnessed worldwide, hydro-meteorological hazards—such as cyclones, floods, heatwaves and various forms of droughts—have caused major negative socio-economic impacts and consequences throughout history. This situation has been worsening due to a trajectory of socio-economic development and politics, such as population and wealth increases along coasts and lack of investment in reduction and preparedness measures (Barthel and Neumayer, 2012; Klotzbach et al., 2018; Neumayer and Barthel, 2011; Neumayer et al., 2014; Pielke, 2019; The World Bank and the United Nations, 2010), and individual and collective decision-making (Adger et al., 2005; Neumayer et al., 2014) which ignore the risks posed by hydro-meteorological hazards. Climate change is further challenging the situation, emphasising the urgent need to develop and implement governance structures, policies (Amundsen et al., 2010; Bauer et al., 2012; Burton et al., 2002; Corfee-Morlot et al., 2011; Djalante et al., 2013; Urwin and Jordan, 2008) and measures (Carter et al., 1994; Hallegatte, 2009; Smit et al., 2000) that aim at tackling the root causes of disasters and reducing the risk of weather events and climate change (Alexander and Davis, 2012; Eriksen and O'Brien, 2007; Pielke, 2005; Wisner et al., 2003).

Natural hydro-meteorological hazards or weather and climate extremes[1], pose risks to various assets: ecosystems, the lives and livelihoods of people, communities, infrastructure, cultural heritage, the economy and societies in general (IPCC, 2012). Depending on the scale of the hazard, and particularly the underlying factors, the hazard may escalate to a disaster; "Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery" (IPCC, 2014a;. p.1763). Hazards turn into disasters through complex interactions between underlying socio-economic, political and cultural factors, which largely contribute to the creation of risk caused by extreme events (Alexander and Davis, 2012; Wisner, 2016; Wisner et al., 2003).

Meanwhile, due to various anthropogenic processes (Edenhofer et al., 2014), greenhouse gas (GHG), such as carbon dioxide (CO_2) and methane (CH_4), concentrations in the atmosphere have substantially increased. For instance, the CO_2 concentration has increased from an estimated 285 ppm (parts per

[1] also called extreme, severe, rare or high-impact weather or flood events (Stephenson, 2008), climate extremes, weather and climate variability (IPCC; 2012)

million[2]) in 1850[3] to 413 ppm in April 2020[4]. This is changing the global energy balance and the flow of energy through the climate system; altering the circulation patterns of the atmosphere, modifying the hydrological cycle, rising global sea level and also leading to changing weather and climate extremes[5] (Stocker et al., 2013). Furthermore, other anthropogenic factors, such as urbanisation (Peng et al., 2012), land use change (e.g. vegetation change) (Cornelissen et al., 2013; Pielke Sr et al., 2011; Pielke Sr, 2005; Swingland. et al., 2002), black carbon (Bond et al., 2013) and aerosol emissions (Rosenfeld et al., 2008) are changing climatological and hydrological patterns at regional and local scales. Amplifiers, creating positive feedback loops, occur naturally in earth systems and may further speed up the consequences of anthropogenic or natural triggers (Alley et al., 2003; Kutzbach et al., 1996). Evidence shows that climate change can already be attributed to the changing probability of individual hydro-meteorological events (Stott et al., 2015; Trenberth et al., 2015; Otto et al., 2018), but the evidence is more unclear whether climate change has contributed to the increasing socio-economic impacts and consequences of climate-related hazards (Barthel and Neumayer, 2012; Changnon et al., 2000; Gleditsch, 2012; IPCC, 2014b, ch. 18; Klotzbach et al., 2018; Neumayer and Barthel, 2011; Pielke Jr, 2019; Sander et al., 2013;).

The atmosphere is a global common pool resource (Dietz et al., 2003; Hanley et al., 1997; Nordhaus, 1982; Ostrom et al., 1999). Most importantly, it possesses the property of non-excludability: consumption of the atmosphere as GHG storage by one does not exclude others from consuming it. As witnessed with many other common pool resources, the atmosphere is subject to the 'tragedy of the commons' (Hardin, 1968; Milinski et al., 2002), i.e., overuse as witnessed by ongoing, anthropogenic climate change. Therefore, as opposed to pure public goods which share both the properties of non-excludability and non-rivalry (Samuelson, 1954), climate policy with specific GHG reduction targets has turned the atmosphere into a rivalrous good. Thereby, GHG emissions emitted to the atmosphere by an individual, a household, a factory, a firm, a farm, or at the aggregate level of a country exhaust the possibilities of other economic agents to emit without increasing the levels of the atmospheric GHG composition; thus, changing the current balance of the climate system at a pace that humans and ecosystems may not be able to adapt to (Kates et al., 2012; Ramanathan and Feng, 2008; Schellnhuber, 2008; Weitzman, 2011).

To a large extent, global climate change caused by the accumulation of GHGs in the atmosphere is a negative externality. It is predicted to create various, potentially very negative consequences on ecosystems and economic agents

[2] dry mole fraction defined as the number of molecules of carbon dioxide divided by the number of molecules of dry air multiplied by one million
[3] https://data.giss.nasa.gov/modelforce/ghgases/Fig1A.ext.txt [Accessed 17 May 2020]
[4] https://climate.nasa.gov/vital-signs/carbon-dioxide/ [Accessed 17 May 2020]
[5] due to the decreasing amount of thermal radiation from land and oceans radiated back to space

(IPCC, 2014b, ch.18). As with any externality (Pigou, 1928), the agents causing climate change, and particularly the negative consequences of climate change, are often not the same agents who bear the consequences (Stern et al., 2006). As noted by Tol (2009, p. 29), "climate change is the mother of all externalities"; it is a complex, highly uncertain and potentially a large societal challenge in which efforts to solve are complicated by various political and technological challenges (e.g. Knutti et al., 2016; Pindyck, 2013; Weitzman, 2011, 2009).

Major global political efforts have been taken to reduce the risks posed by disasters and climate change. The 2005 Hyogo Framework for Action (UNISDR, 2005) and the more recent Sendai Framework for Disaster Risk Reduction (UNISDR, 2015a), adopted in 2015, lay the foundation for global efforts in multi-hazard disaster risk reduction (DRR) and disaster risk management (DRM). The Paris Agreement approved in COP[6]23, in 2015, and its ratification by 185 countries (Parties to the United Nations Framework Convention on Climate Change in 1992) is the most recent sign of global political will to tackle the challenge of climate change.

Climate change mitigation, i.e. the reduction of GHG emissions from energy, land use and other sources (Edenhofer et al., 2014), is currently attracting most of the academic and, in particular, political attention. However, in practice, various challenges, such as the lack of political ambition (Rogelj et al., 2016), lack of cooperation and coordination in global climate policy (Harris, 2007; Keohane and Victor, 2016; Nordhaus, 2015; Weitzman, 2015), lack of technologies to reach a required level of GHG emissions (Arvesen et al., 2011; Fuss et al., 2016), individual preferences and behaviour[7] have maintained an increasing rate of GHG emissions. Therefore, despite the stated political will to halt the increase of GHG emissions since the first climate negotiations (COP1) in 1995, they have been steadily increasing[8]. This has emphasised the urgency and challenges related to policies and measures that aim at reducing the socio-economic impacts of hydro-meteorological events, i.e climate change adaptation (CCA) (Adger et al., 2005; Hallegatte, 2009; Pielke Jr et al., 2007; Smit et al., 2000; Tol, 2005). On the one hand, climate change mitigation and CCA are efforts to tackle the impacts of climate change: mitigation reduces our need for CCA, and vice versa (Kane and Shogren, 2000; Tol, 2005). Academic research has developed models that account for the complementarity of mitigation and CCA for effective management of climate change risk, resulting in an economically optimal mix of mitigation and CCA (see Kane and Shogren, 2000).

On the other hand, to prevent, reduce and prepare for disaster risk and to respond to and recover from disasters associated with natural hazards and

[6] Conference of the Parties
[7] https://www.iea.org/newsroom/news/2019/october/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-mark.html [Accessed 17 May 2020]
[8] https://climate.nasa.gov/vital-signs/carbon-dioxide/ [Accessed 17 May 2020]

climate change, there are two, often separately addressed fields of research, policy and practice: DRM and CCA (IPCC, 2012, 2014a). DRM and CCA in human systems share the objective of reducing the impacts of weather and climate extremes through focusing on the exposure and vulnerability of people and assets at risk and improving disaster response and recovery. This is done by developing improved and integrated policies and strategies, implementing measures through investing in technological development and innovations, and encouraging the adoption of behavioural change at an individual level (Gero et al., 2011; IPCC, 2012; Mendelsohn, 2012, 2000; Pielke Jr et al., 2007; Tol, 2005) (see Section 2.1 for definitions for DRM and CCA). The benefit of CCA in terms of DRM is that it brings a long-term perspective to the traditional DRM approach (Ireland, 2010; Kelman et al., 2015; Mercer, 2010; Rivera & Wamsler, 2014; Schipper 2011; Venton & La Trobe 2008).

Despite the potential to increase the efficiency and effectiveness of DRM and CCA through their integration in research, governance and practice (Venton & La Trobe 2008), integration is still in its infancy (Ireland, 2010; Kelman et al., 2015; Mercer, 2010; Rivera & Wamsler, 2014). Challenges behind the lack of integration have been identified (Gero et al., 2011; Mercer, 2010; Rivera & Wamsler, 2014;), but no precise definition for the relationship between DRM and CCA and their joint integration, or mainstreaming, in other policy fields exist within the integration literature. Furthermore, empirical accounts of DRM and CCA integration are still scarce. Vulnerability reduction is at the core of DRM and CCA, but its realisation is often challenged by low quality governance (UNISDR, 2015b) which is interlinked with other socio-cultural factors (Alexander & Davis, 2012). The majority of the literature on governance challenges has focused on economically less developed countries, with less analysis on effective governance in wealthier countries. The literature also lacks analysis on the complexity of DRM and CCA governance owing to multiple, competing decision-making criteria: effective implementation of DRM and CCA governance and implementation does not necessarily imply cost-efficiency, resulting in potential over-adaptation to disasters and climate change (Hanemann, 2000). Furthermore, governance and improved DRM and CCA measures do not lessen the importance of the role of decision-making down to the level of the individual in reducing the impacts of natural hazards, disasters and climate change (Adger et al., 2005).

The academic literature has discussed the complexities of DRM for a long time (e.g. White, 1945) and more recently CCA (Adger et al., 2005; 2009; IPCC, 2014b ch.16). In this thesis, I identify and address challenges related to DRM and CCA policies, governance, measures, and their implementation, specifically related to i) DRM and CCA policy integration, ii) the governance of vulnerability reduction and iii) cost-efficiency and effectiveness of DRM and CCA measures.

1.2 Research Question and Objectives

This thesis investigates the following question: what are the means to overcome the salient challenges in DRM and CCA policies and measures that are designed to reduce the risks posed by extreme weather under uncertainty? This question is examined from multiple angles leading to the following research objectives:

- To identify and analyse the challenges related to DRM and CCA integration, and their further integration into sectoral policies, to ensure efficient and effective reduction of extreme weather events and climate change impacts;

- To explore how governance, other socio-cultural structures, policies and their implementation can effectively reduce disaster risk and climate change by using the Nordic welfare state as an example of a success story in DRM and CCA;

- To analyse the efficiency, effectiveness and social acceptability of DRM and CCA measures under future uncertainty.

The thesis contributes to the literature in the following ways. Conceptually, it provides a definition for DRR and CCA integration and their integration to sectorial policies, and an economic definition for over-adaptation to climate change. Empirically, it contributes to i) the scarce literature on the challenges of policy-level DRM and CCA integration and their integration into sectoral policies, ii) the literature on how DRM and CCA approaches are implemented in Finland and whether current vulnerability and exposure assessments neglect some risks or hinder the seizing of opportunities brought by climate change; and iii) the empirical economic literature on DRM and CCA measures under uncertainty.

1.3 Approach

The research question and objectives are addressed in four articles which analyse DRM and CCA governance and measures from economic and policy perspectives, yet cover different empirical foci, methods, data and geographical scopes. Table 1 shows the data and methods used in the articles and how risk and uncertainty are addressed for DRM and CCA.

Table 1. Data, methods and approaches to risk, uncertainty, DRM and CCA

PAPER	DATA	METHODS	RISK AND UNCERTAINTY	DRM & CCA
I	Interviews and policy documents	Coding of qualitative data	Risk from natural hazards and climate change; uncertainty due to climate change	Policy integration for effective and efficient DRM and CCA
II	Interviews and policy documents	Exploratory case study	Risk from natural hazards and climate change; uncertainty not formally analysed	DRM and CCA policy analysis
III	Quantitative data	Cost-benefit Analysis; Monte Carlo Analysis	Storm risk on electricity network; uncertainty in parameter values due to future uncertainty	Cost efficiency of an integrated DRM and CCA measure
IV	Interviews and literature	Interview coding and quantitative calculation of monetary benefits; sensitivity analysis	Risk of changing weather conditions; uncertainty of climate change impacts	Economic benefits of a CCA measure

Article I addresses the level of DRM and CCA policy integration as a means for the effective and efficient management of weather and climate change related risks in Zambia. It focuses on DRM and CCA capacities; the status of DRM and CCA policy integration and the level of budget allocation for DRM and CCA. Uncertainty is not explicitly analysed, but the article is framed to address the increasing uncertainty of natural hazards due to climate change. The situation regarding the level of integration is analysed at horizontal (inter-ministerial) and vertical (intra-ministerial) dimensions, leading to an assessment of the challenges regarding effective integration. Article II discusses the contribution of the underlying risk drivers of governance, societal and political factors, culture, policies and their implementation to DRM and CCA. The article describes the Finnish model, the role of governance and society for DRM and CCA and assesses how the model, or more broadly the Nordic Welfare state model, can effectively reduce vulnerability to natural hazards. Article III furthers the analysis of the Finnish approach to DRM and CCA through a social in medias res/ex-post cost benefit analysis on the Finnish Electricity Market Act 2013 (Sähkömarkkinalaki 588/2013, 2013), which defines strict limitations to, mostly, storm and snow induced power outages and has therefore contributed to major investments in weather-proofing the electricity distribution network, partly aiming at effective reduction of weather-induced impacts. Furthermore, Article III describes the public response to the Act. Risk and uncertainty are key concepts of Article IV as uncertain changing climate will pose new risks to the road transport sector. Due to the uncertainty, robust methods are needed to reduce the risk in the changing conditions. Uncertainty is addressed through sensitivity analysis. Article IV has been framed from CCA perspective, but improved weather services will reduce the risk of weather also in the current climate, thereby contributing also to the improved reduction of extreme weather event impacts in the current climate.

The articles apply both qualitative and quantitative methods to analyse the research question, elaborated in section 3. Mixed methods research is an approach which uses both quantitative and qualitative approaches to seek answers to the research question of interest (Johnson and Onwuegbuzie, 2004) (See section 3.1 for more detail). Qualitative methods are used because of the need to understand how policies are situated and embedded in their implementation context, to identify how contextual factors influence policy processes (Sadovnik, 2007) and to efficiently obtain explicit and tacit knowledge from experts. Quantitative policy analysis with economic methods is used because of the need to address efficiency, cost-effectiveness and the economic benefits of DRM and CCA measures at public and individual decision-making levels (Konrad and Thum, 2014).

Articles I and II are examples of studies using purely qualitative data and analysed with qualitative methods, described in more detail in section 3.2. In Article I, the data consists of interviews and policy documents used to analyse the integration of DRM and CCA policies in Zambia. In Article II data was collected through an online survey, semi-structured interviews and workshops in two research projects which was used to analyse weather and climate related risks in Finland. Both articles analyse the data qualitatively; Article I uses a systematic qualitative method described in section 3.2, whereas Article II uses an explorative method (Baxter and Jack, 2008; Stebbins, 2001) and aims to contribute to the literature by constructing a fresh viewpoint and discussing its implications. Article III uses quantitative data and analyses it with quantitative methods, described in more detail in section 3.3. Article IV combines qualitative and quantitative approaches. Qualitative interviews and document data has been converted into a quantitative assessment on the potential economic benefits of innovations in weather service provision in the road transport sector.

2 THEORETICAL BACKGROUND ON DISASTER AND CLIMATE RISK MANAGEMENT UNDER UNCERTAINTY

2.1 Disaster Risk Management and Climate Change Adaptation - Policies and Implementation

Disaster Risk Management (DRM) related to hydro-meteorological events and Climate Change Adaptation (CCA) aim at i) reducing people's and societies' vulnerabilities and exposure to the impacts of natural hazards and ii) increasing their capacity to reduce the risk and prepare for, respond to and recover from disasters. Broadly speaking, both fields share the objective of reducing the human impacts of weather and climate extremes by addressing exposure, underlying vulnerability and enhancing the resilience of affected people and assets (Schipper 2009; Rivera & Wamsler, 2014; Gero et al., 2011, IPCC, 2012; Kelman et al., 2015). Policies, strategies and measures to decrease exposure and vulnerability and increase capacity are at the core of DRM and CCA (IPCC, 2012). Typically, DRM and CCA are addressed, studied and analysed separately (Ireland, 2010; Kelman et al., 2015; O'Brien et al., 2006), despite their multiple overlaps and synergies (Mercer, 2010; O'Brien et al., 2006; Solecki et al., 2011).

In the field of disaster and CCA studies, four key terms are relevant: Disaster Risk Reduction (DRR), Disaster Management (DM), DRM and CCA. The definitions of these terms by the two key United Nations organisations, the Intergovernmental Panel on Climate Change (the IPCC) and the United Nations Office for Disaster Risk Reduction[9] (UNDRR), are given in Table 2. The definitions are ambiguous, differing and overlapping on two levels: the scope and object. As per the scope, both the IPCC (2014a) and UNDRR agree on DRR being defined in terms of a policy objective but differ as the IPCC includes strategic and instrumental measures (the object) in DRR. As per the scope, the main difference is in the definition for DRM, as the UNDRR[10] defines DRM's scope to be the same as DRR's scope: to "prevent new disaster risk, reduce existing disaster risk and manage residual risk", whereas the IPCC (2014) defines DRM to "improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices".

[9] Formerly the UNISDR; the dedicated UN secretariat to facilitate the implementation of the International Strategy for Disaster Reduction (ISRD)
[10] https://www.undrr.org/terminology [Accessed 17 May 2020]

Table 2 The IPCC (2014a) and UNDRR glossary definitions for key terms

	IPCC 2014 Glossary (IPCC, 2014a)	UNDRR Definition & Annotation (UNDRR glossary[11])
Disaster Risk Reduction (DRR)	"Denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience."	"[...] is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development." "[...] is the policy objective of disaster risk management, and its goals and objectives are defined in disaster risk reduction strategies and plans."
Disaster Management (DM)	"Social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve disaster preparedness, response, and recovery practices at different organizational and societal levels."	"The organization, planning and application of measures preparing for, responding to and recovering from disasters." "[...] may not completely avert or eliminate the threats; it focuses on creating and implementing preparedness and other plans to decrease the impact of disasters and "build back better". Failure to create and apply a plan could lead to damage to life, assets and lost revenue."
Disaster Risk Management (DRM)	"Processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, and sustainable development."	"[...] is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses." "[...] actions can be distinguished between prospective disaster risk management, corrective disaster risk management and compensatory disaster risk management, also called residual risk management."
Climate Change Adaptation (CCA)	"The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities."	Not provided

This thesis follows the IPCC (2014a) definitions, because the three components of DRM, DRR, DM are clearly defined and the IPCC (2014a) also includes a definition for CCA. DRM is an umbrella term to encompass the entire spectrum from DRR to DM. DRR places focus on anticipating future disaster risk and reducing existing risks through a set of policies, objectives and measures developed and implemented before the disaster occurs by mitigating and reducing hazard, exposure and vulnerability. DM places focus on preparing, responding to and recovering from disasters in the phase when the threat of disaster becomes evident. However, the distinction is ambiguous as in some cases, DRR and DM overlap. For instance, the concept of 'Build

[11] https://www.undrr.org/terminology [Accessed 17 May 2020]

Back Better' aims at reducing the risk of future disasters (DRR according to IPCC, 2014a) during the post-disaster recovery phase (DM according to IPCC, 2014a) (Mannakkara & Wilkinson 2015; Wisner 2017; Dube 2020). Noteworthy is that the IPCC (2014a) DRM definition is more explicit on how to reduce risk than the CCA definition, whereas CCA also includes the potential benefits gained from climate change. As implied in the IPCC's DRM definition, it constitutes actions taken at various spatial scales from international agreements to decision-making at an individual level. Although not explicitly stated in the CCA definition, the same applies for CCA as well (e.g. Adger et al., 2005).

At the policy level, the importance of integrating, or mainstreaming CCA policy goals across all relevant policy domains and strategies has been highlighted by researchers (Bauer et al., 2012; Ogallo, 2010; Urwin and Jordan, 2008) and policy-makers, for instance, in the European Union (COM, 2013). The integration of DRM policy goals has not received similar attention in academia, although the role of social protection and other relevant vulnerability reduction policies has been shown to reduce vulnerability to various weather-induced impacts (Devereux, 2016). Policy integration has its roots in Environmental Policy Integration (Jordan and Lenschow, 2010; Mickwitz and Kivimaa, 2007; Nilsson and Persson, 2003; Nunan et al., 2012; Oberthür, 2009), where integration has been widely recognised as an important approach to promote environmental concerns in policy making. Climate Policy Integration (CPI) has traditionally referred to integrating climate change mitigation goals in relevant sectorial policies and strategies (Adelle and Russel, 2013; Dupont and Oberthür, 2012; Ishii and Langhelle, 2011), but as noted, CCA integration, or mainstreaming, has also gained attention.

Measures to reduce the impacts of disasters and climate change have been, for the most part, categorised from a CCA perspective. Various, partly overlapping typologies for CCA in human systems exist. For instance, Konrad and Thum (2014) provide a categorisation of CCA measures based on economic principles; Hallegatte (2009) bases his categorisation on economic rationale in the face of uncertainty regarding climate change. Carmin and Dodman (2013) categorise CCA measures into three types: i) structural/concrete, ii) institutional and iii) social. Furthermore, CCA can be either incremental, if the system is changed by merely extending the current practices, or transformational, if adaptation entails far reaching systemic changes (Kates et al., 2012; see O'Brien, 2012 for a thorough description on deliberate transformation). Smit et al. (2000) propose a simple definition for CCA by assessing three questions: i) *Adaptation to what*, ii) *Who or what adapts* and iii) *How does Adaptation occur*. In principle, an extension of these three questions is useful for categorising the various typologies of CCA measures.

The majority of the typologies answer the question "*which types of strategies or measures are available*" (Biagini et al., 2014; Carmin and Dodman, 2013; Hallegatte, 2009; IPCC, 2012). The typology by Konrad and Thum (2014) is a hybrid; it categorises CCA measures based on the most common question "*which types of strategies or measures are available*" but also on "*Who (or what) adapts and Who (or what) benefits*" (also Mendelsohn, 2000; Smit et al., 2000 and empirically in Fidelman et al. (2013)) and "*when does adaptation take place*" (Fankhauser et al., 1999) (also Carter et al., 1994 and Smit et al., 2000). Lastly, incremental vs transformative typologies respond to "*what is the degree of change required?*" Although the academic articles providing typologies for CCA measures have all been framed from a CCA perspective, the measures used as examples are all also DRM measures, implying that they would also yield benefits in the current climate. Therefore, it is beneficial from efficiency and effectiveness perspectives to ensure that the policy measures used to reduce the current risks of extreme weather events fulfil the criteria of robustness in the face of deep uncertainty related to climate change and socio-economic factors (Hallegatte, 2009; Hallegatte et al., 2012; Kelman, 2017; Kelman et al., 2015; Mercer, 2010; Schipper, 2009).

2.2 Risk and Uncertainty

Risk and uncertainty are some of the defining factors of our existence: they shape our thinking, decision-making and behaviour. Risk and uncertainty have motivated academics to develop theories (e.g. Expected utility theorem (von Neumann and Morgenstern, 1944), Portfolio theory (Markowitz, 1952), Prospect theory (Kahneman and Tversky, 1979), Risk society (Beck, 1992) and the Black Swan theory (Taleb, 2007)) and industry to create an entire industrial sector: finance and particularly the insurance sectors. Disaster and climate change risk have inspired writers (e.g. *Science in the Capital* trilogy[12] by Kim Stanley Robinson) and film makers (e.g. *The Day After Tomorrow* by (Emmerich, 2004) and *Geostorm* (Najafi, 2017)). Inherently, risk and uncertainty are something that we constantly deal with and the way we deal with it depends on our preferences (Arrow, 1971; Pratt, 1964) and intuition (Kahneman & Tversky, 1979).

2.2.1 Probabilistic Risk Analysis

Depending on the research field, risk and uncertainty are often defined and treated in different ways. In neoclassical economics, the distinction between risk and uncertainty is vague, yet based on a strictly probabilistic treatment of uncertainty (Mas-Colell et al., 1995, ch.6). In principle, a risky situation is a decision situation which involves some, specified level of uncertainty. Expected utility theorem (von Neumann and Morgenstern, 1944) and subjective probability theory (Savage, 1954) are both based on the idea that modelling decisions involving an element of risk starts from the notion that in an uncertain environment the decision-maker holds two types of information:

[12] *Forty Signs of Rain* (2004); *Fifty Degrees Below* (2005); *Sixty Days and Counting* (2007)

i) all possible, uncertain outcomes of the decision made under uncertainty, and ii) a vector of probabilities for each possible outcome; where $p_s \geq 0$ are the probabilities of occurrence of x_s with $\sum_{s=1}^{S} p_s = 1$. (Gollier, 2001, p. 4).

Expected utility theorem assumes that the vector of probabilities for each possible outcome can be summarized by means of objective numerical probabilities by the decision-maker. If we let $A = \{a1, \dots a_N\}$ be the set of all possible outcomes which involve some source of uncertainty and $p_i \geq 0$, where p_i represents the uncertainty as the probability of outcome a_i occurring, a simple lottery is a list $L = (p_1, \dots, p_N)$ with $p_n \geq 0$ for all A. Simply put, the set of simple lotteries is given by the probability of each outcome multiplied by the outcomes in question. (Mas-Colell et al., 1995) The main purpose of expected utility theorem is to assess choice under uncertainty assuming certain decision-maker preferences over the uncertain outcomes.

In *subjective probability theory*, the assumption on objectively known probabilities is relaxed to incorporate the fact that the reality is hardly ever based on objectively known probabilities. In subjective probability theory, individuals hold beliefs over the likelihood of various outcomes and through choices reveal these beliefs in a well-defined probabilistic manner. Thereby, subjective probability theory can be considered a "far-reaching generalisation of expected utility theory". (Mas-Colell et al., 1995, p. 205).

Risk is most commonly defined as the probability of an adverse event (e.g. a natural hazard) times its consequences:

$$R = p_i \, Ci \, Vc, \qquad [1]$$

where i is a certain event; C is the expected outcome of the event; and in case of economic damage, V is the economic value of the outcome. (Renn, 1998; Rosa, 1998). Hydro-meteorological processes are often used as an example of risk and uncertainty in literature on decision-making under risk. Typically, historical hydro-meteorological events can be expressed in probabilities (e.g. return periods which express the likelihood of an event happening in a certain time period) (e.g. Kunkel et al., 1999b, 1999a) and are therefore a convenient expression of risk for decision-making science. For instance, a decision-maker may face an investment decision for a dam when they know that the yearly probability for wet and dry years is 0.3 and 0.7, respectively (Graham, 1981). These probabilities are usually derived from historical observations and, in the best case, can be considered relatively objective.

This definition, however, does not explicitly address the underlying risk drivers: exposure, vulnerability and capacity, even though implicitly incorporated in p_i and C_i (IPCC; 2012). Explicit treatment of the underlying risk drivers is crucial for the development of DRM and CCA policies and measures. As noted by Wisner et al. (2003, p. 4), disasters are "the product of social, political and economic environments because of the way these structure the lives of different groups of people". This has led to the use of the following extended frameworks of traditional probabilistic risk analysis in DRM and CCA fields.

2.2.2 Extensions of the probabilistic risk analysis

Two widely adopted, partly overlapping theoretical frameworks which are the most relevant for this thesis are the IPPC (2014) and UNDRR risk frameworks, the Pressure-and-Release Model (PAR) and, its extension, the Access model (Wisner et al., 2003). All these focus, to a varying degree, on the underlying risk drivers behind natural hazards and climate change.

The IPCC (2014) framework, adopted by the IPPC in 2012 (IPCC; 2012), is used by the United Nations Global Risk Data Platform[13]—also widely in climate risk assessments (UNISDR, 2017)—and defines risk as being a function of hazard, exposure and vulnerability. The UNDRR[14] also includes capacity. In the IPCC (2014) framework, hazard is a hydro-meteorological event or gradual climate change and is typically described by the (joint) statistical distribution of various climatological parameters (IPCC, 2012; Katz and Brown, 1992). Climate is defined as the "the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years" and as "the state, including a statistical description, of the climate system" (IPCC, 2014a, p. 1760). Climate describes the statistical properties of various surface weather parameters, over a certain period, usually 30 years (World Meteorological Organization, 2008). Climate change refers to changes in the statistical properties of the climate parameters, in the mean and/or in the variability of the statistical properties of the climate (IPCC, 2014a). There is no precise statistical definition for an extreme event, as a probabilistically extreme hydro-meteorological hazard may not cause extreme socio-economic impacts, and the definition of extreme depends on temporal and spatial scales (e.g. IPCC, 2012, p. 117; Stephenson, 2008).

The remaining components in the risk equation are constructions of socio-economic, cultural, political and other anthropogenic processes. Table 3 shows the IPCC (2014a) and UNDRR definitions for the key risk components. Noteworthy is that the IPCC (2014a) definitions have changed since the Managing the Risks of Extreme Events and Disasters to advance Climate Change Adaptation report (IPCC, 2012), where the definitions were closer to the UNDRR definitions.

[13] https://preview.grid.unep.ch/ [Accessed 17 May 2020]
[14] https://www.undrr.org/terminology [Accessed 17 May 2020]

Table 3. The IPCC (2014a) and UNDRR definitions for Risk, Exposure, Vulnerability and Capacity

	IPCC 2014a		**UNDRR Definition & Annotation**	
(Disaster) Risk	"The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. [...] Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of climate-change impacts."		"The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity."	
Exposure	"The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected."		"The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas."	
Vulnerability	"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. "		"The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." "Annotation: For positive factors which increase the ability of people to cope with hazards, see also the definitions of "Capacity" and "Coping capacity""	
Capacity	**Adaptive capacity** "The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences"	**Coping capacity:** "The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term."	**Capacity** "The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience."	**Coping capacity** "The ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks."

In principle, the IPCC (2014a) and the UNDRR agree on the concept of exposure: it refers to people and assets being located in places, such as coastal areas, small islands or urban areas, where a hazard may occur. Vulnerability, however, is an ambiguous concept and the challenges related to defining and empirically assessing vulnerability have been discussed in detail in literature (Bogardi, 2006; Wisner, 2016). The IPCC (2014a) definition for vulnerability highlights this ambiguity, because it does not define, as opposed to the UNDRR (also in IPCC; 2012), any attributes/factors/conditions which contribute to people and societies being vulnerable to natural hazards and climate change (Wisner, 2016). Nevertheless, exposure is a necessary, yet not a sufficient, condition for disaster risk as it is possible to be exposed to a hazard but to have sufficient means to reduce vulnerability to a level where impacts are not experienced (IPCC, 2012).

The main difference between the IPCC (2014a) and UNDRR definitions for risk is the capacity component. Indeed, it may be argued that capacity is just another side of the vulnerability coin and the inclusion does not provide any added value to the definition. However, as explained in Wisner et al (2003), the situation is more nuanced: vulnerable people and communities have capacities that are not captured if the focus is only on vulnerability. This also applies at larger scales; e.g. communities and countries. Therefore, capacity, as a separate analytical component, increases our understanding of the complex notion of risk.

Various mathematical formulations for the definition of risk exist. Peduzzi et al. (2009) assume that risk follows a multiplicative formula as follows:

$$R = H_{fr}\ x\ Pop\ x\ Vul \qquad [2]$$

where: R = number of expected human impacts [killed/year]. H_{fr} = frequency of a given hazard [event/year]. Pop = population living in a given exposed area [exposed population/event]. Vul = vulnerability depending on socio-politico-economical context of this population [non-dimensional number between 0–1]. The formula shows that if any of the factors H_{fr}, Pop, Vul = 0, then the risk is null. This formulation of the risk focuses solely on the risk of human casualties. A generalised form is given in e.g. Carrão et al. (2016):

$$R = Hazard\ x\ Exposure\ x\ Vulnerability \qquad [3]$$

where all the three components are normalised to [0,1]. Noteworthy is that the mathematical notions in the literature neither include capacity a risk component, nor do they explicitly include the notion that the risk components are a function of time, *t*, and space, *s*. Therefore, a generalised representation of eq [1] is as follows:

$$R = f(hazard_{s,t,}, exposure_{s,t}, vulnerability_{s,t}, capacity_{s,t}), \qquad [4]$$

where R denotes risk.

The second, the PAR model, widely used in the disaster field goes deeper in the societal processes and root causes which put people in vulnerable positions. It defines disaster risk as Risk = Hazard x Vulnerability; a definition used also by the IPCC before 2012. Vulnerability is decomposed to three parts: i) root causes, ii) dynamic pressures and iii) unsafe conditions. It includes the exposure and capacity factors from the IPCC (2012) framework as part of vulnerability. All the risk components are functions of time and space (Cutter and Finch, 2000; Wisner et al., 2003). and the PAR model, even though not mathematically defined as functions, analyses the different components implicitly as functions of time and space. The extension of the PAR, the Access model, provides a more detailed analysis of the economic, social and political processes that create vulnerability to hazards. The main addition to the IPCC (2014a) and the UNDRR vulnerability definition is the inclusion of political processes as an important vulnerability factor (See also Wisner, 2016). Hazard is defined similar to the IPCC framework in a probabilistic way (Wisner et al., 2003).

2.2.3 Uncertainty

Various definitions for uncertainty exist. Relevant for this thesis is the distinction between two forms of uncertainty: measurable and unmeasurable. Measurable uncertainty can be expressed, one way or another, in a probabilistic form and was introduced in section 2.2.1. The idea being that uncertainty—and the subjective uncertainty regarding the uncertainty—can be measured is visible for instance in the latest IPCC uncertainty definition. It expresses uncertainty as something that can be quantitatively measured or qualitatively assessed:

> "A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts)" (IPCC; 2014a, p. 1774).

However, the notion of uncertainty with objectively or subjectively known or estimated probability distributions and subjective confidence intervals, including clear definitions for complex socio-cultural and political factors and processes as defined by the IPCC, ignores the multitude of challenges related to disaster and climate change risk assessments.

The distinction between measurable and unmeasurable uncertainty was first formally suggested by Knight (1921). He notes that

> "...Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk [...]. The essential fact is that "risk" means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomenon depending on which of the two is really present and operating. There are other ambiguities in the term "risk" as well [...]; but this is the most important. It will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all."

In climate change literature, the unmeasurable uncertainty, so called Knightian uncertainty, is increasingly called deep uncertainty (Hallegatte et al., 2012; Lempert, 2014).

Walker et al (2010, p. 918) describes a categorisation of four levels of uncertainty between the two extremes of determinism, where everything is precisely known and total ignorance where nothing is known about the future:

> "Level 1 uncertainty is any uncertainty that can be described adequately in statistical terms; Level 2 uncertainty implies that there are alternative, trend-based futures and/or different parameterizations of the system model, and some estimate can be made of the probability of each of them; Level 3 uncertainty represents deep uncertainty about the mechanisms and functional relationships being studied; Level 4 uncertainty implies the deepest level of recognized uncertainty; in this case, we only know that we do not know";

Levels 1 and 2 are measurable uncertainties, or risk, according to Knight (1921), and levels 3 and 4 constitute unmeasurable uncertainties. Level 4 uncertainties are also called Black Swan events (Taleb, 2007). Level 3 uncertainty, deep uncertainty, is defined as a situation when "analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate models to describe the interactions among a system's variables, (2) the probability distributions to represent uncertainty about key variables and parameters in the models, and/or (3) how to value the desirability of alternative outcomes" (Lempert et al., 2003, p. 3).

In the disaster and climate change field the following uncertainties are relevant, for instance: i) the current probability distributions of (joint) hydro-meteorological variables to adequately define the hazard probability (Highfield et al., 2013; Morss et al., 2005), ii) parameter values in the changing climate (Morss et al., 2005), iii) analysis of vulnerability and capacity (Wisner, 2016); iv) climate model uncertainties (van Asselt and Rotmans, 2002); v) challenges related to the assessment of the socio-economic impacts of climate change (Thorarinsdottir et al., 2017), vi) evolving societal factors (Morss et al., 2005; van Asselt and Rotmans, 2002); vii) scientific uncertainty due to "complexity, stochasticity, or a fundamental lack of data or understanding" (Morss et al., 2005, p. 1596); and viii) the practical constraints in using uncertain information in policy and decision-making (Morss et al., 2005). Therefore, a probabilistic definition of risk and uncertainty does not capture true, unmeasurable uncertainty which is crucial when we discuss future climate change and adaptation to its impacts (Konrad and Thum, 2014).

For instance, Thorarinsdottir et al. (2017) quantify uncertainty related to sea level rise and associated economic damage for CCA decision-making and conclude that not accounting for uncertainties in climate change impact studies may result in 'bad scenarios' that result in the situation being an order of magnitude worse than what the decision-maker might expect if uncertainty is not accounted for. The analysis is based on several assumptions and simplifications, and shows how difficult, and perhaps impossible, it is to provide a reliable assessment of the socio-economic impacts of climate change.

2.3 Efficiency and Effectiveness

Defining 'successful' DRM and CCA is not an easy task (Adger et al., 2005; Baker et al., 2012; de Bruin et al., 2009). Adger et al. (2005) argue that the four criteria of effectiveness, efficiency, equity and legitimacy of CCA are important in the analysis of success. They note that the criteria are contested, context-specific and based on competing values.

Economists tend to emphasise efficiency and effectiveness as key criteria in public sector decision-making regarding DRM and CCA (Konrad and Thum, 2014; Mendelsohn, 2000; The World Bank and the United Nations, 2010). Effectiveness of DRM and CCA measures implies that a certain outcome or objectives regarding the reduction of disaster and climate change impacts are achieved. More precisely, cost-effectiveness implies that the outcome or objectives are achieved in the least-cost way. Cost efficiency of CCA is broadly defined as CCA which maximizes net benefits.

Formally, efficient CCA at the private and societal level has been defined in Mendelsohn (2012). Private CCA is a decision taken by an individual that only affects that individual; the costs and benefits of the decision only accrue to the individual. If we assume that strict assumptions on market access, private property rights, lack of externalities and good information hold, individuals choose efficient adaptation by default: If we assume that the preferences of an individual can be represented by utility $\boldsymbol{U}$ being a function of a vector of market goods $\boldsymbol{X}$ and an exogenous climate change component $\boldsymbol{C}$, the individual maximises utility subject to their budget $\boldsymbol{Y}$ and price vector $\boldsymbol{P}$:

$$Max\ U(\boldsymbol{X}, \mathrm{C}), s.t. \boldsymbol{PX} = Y, \qquad [5]$$

The set of demand functions for the individual can be derived by assuming suitable separability assumptions (using Roy's identity) for market goods $\boldsymbol{X}$. The demand for goods $\boldsymbol{X_1}$ is not dependant on climate change, whereas the demand for goods $\boldsymbol{X_2}$, the demand function will shift with changing climate, noted C.

$$\boldsymbol{X}_1 = \boldsymbol{X1}(\boldsymbol{P}, Y)$$
$$\boldsymbol{X}_2 = \boldsymbol{X2}(\boldsymbol{P}, Y, \mathrm{C}) \qquad [6]$$

An individual may choose to purchase some capital good **K,** such as shelter, due to climate change. When buying capital goods, the individual aims at maximising utility over time. By assuming that a single capital good is bought in the first period, but it brings utility over time, the utility maximisation becomes

$$Max \int U_t\,(X,\mathrm{C},K)e^{-rt}dt \qquad s.t. \int [Y_t - P_x X_t]e^{-rt} - P_k K = 0 \qquad [7]$$

Taking the first-order condition of [6], we see that the marginal stream of utility over time from the capital good should equal the price of capital at the optimum:

$$P_K = \int (dU_t(X, \mathrm{C}, K)/dK)e^{-rt}\,dt \qquad [8]$$

Therefore, climate change will affect the consumption of the capital good K if the marginal utility from the good depends on climate change.

The efficiency of societal, or public level CCA, where decisions affect many people, is defined in Mendelsohn (2012) by a set of CCA projects that maximize net benefits (Mendelsohn, 2000). For public sector decision-making, the efficient amount of CCA maximises net aggregate benefits:

$$Max \sum B_i(Q) - C(Q) \qquad [9]$$

where $\sum B_i(Q)$ is the aggregate benefits of the CCA project for i agents, and $C(Q)$ is the cost of the CCA project. Maximizing with respect to Q yields the first order condition:

$$MC(Q) = \sum MB_i(Q) \qquad [10]$$

implying that the public sector should implement CCA projects to the point where the marginal cost of the project equals the sum of the marginal benefit of CCA across all individuals. Economically, the optimal set of DRM measures without a changing climate should fulfil the same criteria as for CCA: the efficient set of DRM projects is the set of DRM projects that maximize net benefits.

Climate change will, however, increase the uncertainty related to the criteria of effectiveness and efficiency (Hallegatte et al., 2012; Lempert, 2014; Lempert and Groves, 2010; Sussman et al., 2014b, 2014a). Assessing and achieving effectiveness may not be straightforward because of i) the uncertainties inherent in measuring the effectiveness of 'softer' DRM and CCA measures, ii) the actions taken by agents other than the one implementing the measure and

iii) the uncertainty regarding the future state of the world (elaborated in Section 2.2.3). As noted by Konrad and Thum (2014), there is a risk that a response to expected climate change may initially seem cost-effective but turn out to be expensive or ineffective when climate change does not develop as expected.

This emphasises the challenge related to long-term uncertainty due to climate change, socio-economic and political development (Toth, 2008), as explained in section 2.2.3. Therefore, CCA has been noted as mainly being an iterative process where learning (Baird et al., 2014; Berkhout et al., 2006; Tschakert and Dietrich, 2010) is a key component for successful CCA and initial investments should be put on flexible and robust measures (Dessai and Hulme, 2007; Hallegatte et al., 2012; Lempert and Groves, 2010, Konrad & Thum, 2014). This would potentially avoid the three forms of inefficient and ineffective CCA: under adaptation, over adaptation (Hanemann, 2000) and maladaptation (Barnett and O'Neill, 2010, p. 211): "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups".

To develop policies and measures that perform effectively despite future deep uncertainty, a wide range of plausible scenarios are typically assessed (Walker et al., 2010; Maier et al, 2016) and models to account for deep uncertainty have been developed (Lempert et al., 2003). Based on scenario analysis, robust policies and measures—i.e. those that perform adequately in multiple climatic and societal future scenarios—can be designed and applied; thereby, reducing the current risk and providing benefits in multiple futures despite the deep uncertainty inherent in the climatic and societal systems (Dessai et al., 2009; Fankhauser et al., 1999; Maier et al., 2016). Preparing and reducing the risks of 'Black swan' events (Taleb, 2007), also follows the idea of developing robust, flexible and adaptive systems (Aven, 2015).

Assessing the effectiveness and efficiency is relatively straightforward for concrete DRM and CCA projects, such as a dyke for flood protection. However, public sector DRM and CCA can also refer to less tangible policies and projects, such as Research and Development investments or poverty reduction, where efficiency may not be the sole decision criteria. Furthermore, equity and legitimacy of DRM and CCA are important when defining successful, integrated, DRM and CCA. Equity refers to the distributional effects, or 'fairness' of DRM and CCA decisions (Adger et al., 2005; Hallegatte et al., 2016) and, according to Adger et al (2005, p.83) legitimacy is the "extent to which decisions are acceptable to participants and non-participants that are affected by those decisions".

3 APPROACH: FROM QUALITATIVE TO QUANTITATIVE ANALYSIS

The theoretical background for this thesis illustrates the complexity of the topic. Therefore, the research question is a prime example of a topic which requires the use of mixed methods: a combination of qualitative and quantitative approaches for data collection and analysis to understand the complexity of the issue. As stated in Phillips (2014), both quantitative and qualitative methods are valid ways to study disasters. Furthermore, as stated by Dunn (2015), policy analysis—of which articles I, II and IV can be considered to be a part—is "methodologically eclectic". The main aim of policy analysis should be to produce reliable, policy-relevant knowledge, not to be confined by a certain methodology. Policy analysis should be pragmatic, as the challenges in public policy are economic, political, cultural, ethical and more (Dunn, 2015). This section describes first the justification behind mixed methods research and the qualitative and quantitative research approaches used. All data and methods are described in more detail in the articles.

3.1 Mixed methods research

Broadly categorised, four types of exogenously collected data exist for both quantitative and qualitative research: interviews, questionnaires, documents and observations. Interview transcripts can lead to quantitative data on the content (e.g. word count) or qualitative data in terms of the information obtained from the interviews. Questionnaires can have closed questions leading to quantitative data and open-ended question leading to qualitative data. Documents can be official statistics used for quantitative analysis or can result in quantitative content data. Documents are also a common data source for qualitative analysis and can consist of e.g. policy documents or personal diaries. Observations are the basis for many quantitative analyses, whether the observed variable is "natural" or "societal", and in qualitative research observations can come from, for instance, interactions between people, pictures or events. (Denscombe, 2007) The difference between quantitative and qualitative research is, therefore, not in the data sources but in the nature of the data, or the types of units analysed, and how the analysis is performed. (Robson, 2002).

Both quantitative and qualitative methods have their strengths and weaknesses (see Johnson and Onwuegbuzie, 2004 for a thorough list). The premise of mixed method research is to take advantage of the strengths and minimise the weaknesses (Johnson and Onwuegbuzie, 2004) by being "an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspectives, positions, and standpoints (always including the standpoints of qualitative and quantitative research)" (Johnson et al., 2007, p. 113). As Johnson and Onwuegbuzie (2004, p. 17-18) note, the research question should guide the choice of the research approach: "research methods should follow research questions in a way that offers the best chance to obtain useful answers".

Two major categories of mixed methods research have been defined: *mixed-model* and *mixed-method*. *Mixed-model* implies that the research design mixes qualitative and quantitative approaches within or across the stages of the research process, for instance a questionnaire includes both qualitative and quantitative questions (within) or quantitative analysis is performed on qualitative data (across). *Mixed-method* implies that the overall research design includes both a quantitative phase and a qualitative phase. (Johnson and Onwuegbuzie, 2004) This thesis uses the mixed-method approach, as the overall aim is analysed in parallel both with quantitative and qualitative methods.

3.2 Qualitative approach: Semi-structured interviews and policy documents

Several ways of collecting, processing and analysing qualitative data exist. Interviews are a suitable method for data collection in cases when the research interests are complex and subtler than what, for instance, questionnaires could reveal. Interviews are particularly suitable for situations when the research interest lies in people's opinions, feelings, emotions or experiences (Denscombe, 2007). Policy documents are a common source of data in policy research (Yanow, 2007).

The semi-structured interview is an interview method where the questions are open-ended; the direction or the character of the answer is open and prompts and probes are used in case the interviewer thinks more information could be disclosed (Gillham, 2005). Prompts, on the one hand, are based on other data or previous interviews and are used if the interviewee does not automatically mention something potentially relevant. The use of prompts ensures that all interviews have comparable coverage of issues; however, interviewees need to be prompted in a way so as not to lead their responses. Probes, on the other hand, are supplementary questions or responses that are used during the interview, for example, to clarify, justify or give an example of something that has been raised during the interview. Gillham (2005, p. 70) states that "it could be argued that the semi-structured interview is the most important way of conducting a research interview because of its flexibility balanced by structure". (Gillham, 2005, 2000).

The common steps in qualitative data analysis are: preparing the data, becoming familiar with the data, interpreting the data, verifying the data and presenting the data. The first two steps, preparation and familiarisation, and the last step of presentation are relatively similar to quantitative data analysis; however, the interpretation and verification of data differ notably from quantitative research. Interpretation of the data consists generally of four steps: i) coding the data, ii) categorising the codes, iii) identifying themes and relationships among the codes and categories and iv) developing concepts and arriving at generalised statements (i.e. drawing conclusions). (Denscombe, 2007) Coding of qualitative data is the process of organising and sorting the raw data.

Data verification implies that there needs to be a way to show that the research is credible. Showing credibility in qualitative research is not a simple task; qualitative research, by nature, leaves more room to the interpretations of the researcher and replicability of the research is not necessarily as easy as quantitative analysis. However, research procedures such as triangulation (i.e. using "contrasting data sources to bolster confidence that the data are 'on the right lines'" Denscombe, 2007, p. 297) and an audit trail (i.e. describing the research path and decisions taken during the entire process) are ways to increase the credibility of the qualitative research findings (Denscombe, 2007).

3.3 Quantitative approach: Cost Benefit Analysis

Decision-making at any level is based on certain explicit or tacit knowledge (Herschel et al., 2001; Wyatt, 2001). One tool, or an element, to increase the level of explicit knowledge for decision making is Cost Benefit Analysis (CBA). CBA aims at monetising and, thereby, comparing the various benefits of a policy or a project in terms of its costs. An increase in individual wellbeing is defined as the benefits, and a decrease in wellbeing as the costs. (Arrow et al., 1996; Boardman et al., 2010; Nyborg, 2014)

CBA as a tool is based on general welfare economics, aiming to maximise the aggregate welfare or social utility through the implementation of projects with the highest net economic benefits. Based on the Kaldor-Hicks efficiency criterion, each project is assumed to involve winners and losers; and the gains and losses are aggregated through a social welfare function. The social welfare function is maximised assuming that a 'benevolent dictator', a.k.a. a social planner, ranks the projects according to the efficiency metrics given by CBA and the winners of the project provide compensation of the lost welfare to the losers, yet still remaining better off than without the project (Boadway, 1974; Nyborg, 2014). The Kaldor-Hicks efficiency criterion does not necessarily require actual compensation to be paid; if compensation is paid, the project fulfils the criterion for Pareto improvement (Coleman, 1980) (see a formal presentation of the standard use of CBA for CCA in Nurmi, 2019).

In principle, CBA could work as a social decision rule (not a tool or element) whereby policies and projects are ranked based on the net benefit criterion. This criterion is based on subtracting the project costs from the aggregated benefits, which leads to a simple rule that can be used to compare different projects and decide the one which has the highest net benefit, i.e. the most cost efficient.

Several shortcomings with CBA have, however, been identified. These prevent its use as the only rule in social decision-making (Arrow et al., 1996; Nyborg 2014). The treatment of distributional aspects within and between generations is a fundamental aspect in CBA (Nurmi, 2019), which has been discussed both from theoretical (Boadway, 1974) and ethical (Nyborg, 2014) perspectives. Particularly in climate change mitigation studies, the valuation of inter-generational costs and benefits with the correct discount rate has spurred debate (Arrow et al., 2013; Dasgupta, 2008; Sussman et al., 2014b; Weitzman, 2011, 2001). Other key challenges related to CBA in DRM and, particularly, CCA studies are imperfect benefit valuation methods, tendency to favour monetised costs and benefits, the treatment of non-quantifiable costs and benefits, (Smith et al., 2017), ubiquity of impacts, intangibility, non-marginal changes, long timeframes (Sussman et al., 2014b) and most importantly, uncertainty (Section 2.2.3) (e.g. Graham, 1981; Hallegatte et al., 2012; Li et al., 2014; Smith et al., 2017; Thorarinsdottir et al., 2017). Despite these challenges, Hallegatte et al. (2012) and Sussman et al. (2014b) conclude that CBA has value in decision-making for CCA, particularly as a complementary, supporting tool but its limitations in the assessment phase and interpretation phase should not be ignored.

4 SUMMARIES OF THE ARTICLES

Article I: Defining Climate Change Adaptation and Disaster Risk Reduction Policy Integration: Evidence and Recommendations from Zambia

Article I aims to increase the understanding of Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) policy integration as a means for effective and efficient management of weather and climate change related risks. The study i) defines integration at horizontal (inter-ministerial) and vertical (intra-ministerial) dimensions, ii) refines a policy integration cycle and iii) presents an analytical framework to assess DRR and CCA policy integration in policy formulation and implementation phases. The policy level focus is taken because policies guide actions, and integration at the policy level could deepen the overall integration of DRR and CCA (IPCC, 2012).

The empirical component of the study was undertaken in Zambia. First, the IPCC (2014b) risk framework was used to describe the risk from natural hazards and climate change in Zambia; the risk from natural hazards and climate change is assessed from hazard and climate change, vulnerability and exposure persepctives. Second, the analysis focuses on organisations' roles in, and actors' views on DRR and CCA policy integration to identify potential opportunities for, and challenges to, policy integration. Uncertainty is not explicitly analysed, but the article is framed to address the uncertainty increased by climate change on natural hazards. The data cover semi-structured interviews, policy documents and the government budget plan.

The main contribution of the article is the definition of DRR and CCA policy integration. Following the idea from the literature that CCA policy objectives should be integrated into DRR, and based on the policy integration definitions given in Lafferty and Hovden (2003) and Mickwitz and Kivimaa (2007), the integration of CCA policies into DRR policies can be defined as i) the incorporation of CCA policy objectives into all stages of DRR policy making and ii) accompanied by an attempt to aggregate anticipated impacts of climate change into an overall evaluation of the DRR policy and a commitment to minimise the contradictions between CCA and DRR policies and implementation processes.

Article II: Adaptation by the Least Vulnerable: Managing Climate and Disaster Risks in Finland

Article Paper II focuses on vulnerability reduction as a key to reduce disaster and climate change risk. It addresses the contribution of the underlying risk drivers of governance, societal and political factors, culture, policies and their implementation to DRM and CCA. Most importantly, the role of five factors that constitute 'the elephant in the room' in DRM publications and gatherings, as suggested by Alexander and Davis, (2012) is addressed: the i) human right to hazard information, 2) explosive population growth, iii) corruption, iv) how people are placed at risk by the actions of governments and v) gender discrimination. More specifically, the aim of the article is two-fold: i) to describe the Finnish model and the role of governance and society for DRM and CCA and ii) to analyse and problematise the existing frameworks that guide—or are designed to guide—the theoretical and practical fields of DRM and CCA through the findings of the case description.

The article focuses on vulnerability reduction as a key aspect in reducing disaster and climate change risk. The theoretical contribution furthers discussion on the new dimensions in climate change risk analyses by emphasising the potential impacts of societal development, such as social trends and social cohesion, in effective DRM and CCA. The main contribution is an analysis that focuses on a Nordic welfare state, often forgotten in the literature when addressing the underlying reasons for disaster risk creation.

The risk of extreme weather events and climate change is addressed through the IPCC (2014b) and PAR (Wisner et al., 2003) frameworks. The article provides an insight into a successful case of DRM and CCA, as Finland can be seen as a country where strict public regulation, societal progress and major investments in ensuring that all vital societal functions work in exceptional situations have resulted in a country where natural hazards do not turn into disasters and where climate change may actually bring beneficial opportunities if successfully harnessed. Uncertainty is not explicitly studied, but the role of uncertainty due to climate change and its impacts, and changes in societal structures in the risk analysis frameworks is implicitly discussed.

The article concludes that disaster risk assessments need to be contingent and account for social and economic contexts. In an institutionally well-functioning welfare society, vulnerability assessments should emphasize relative changes in perceived social trends and social cohesion. Exposure should not be limited to direct geographical or physical exposure to local natural hazards. Successful opportunity identification can help improve DRM at home and abroad.

Article III: Overadaptation to Climate Change? The Case of the 2013 Finnish Electricity Market Act

Article III serves as an example of the Finnish approach to DRR and CCA, described in Article II. First, Article III provides a mathematical definition for economic over-adaptation; i.e. the marginal benefits of the investment to reduce disaster risk and adapt to climate change exceed the marginal cost of the DRR and CCA policy measure.

Second, an illustrative case is provided in which the response to extreme weather risk, while aligned with the goals of CCA, is implemented beyond the economically efficient scale. The article provides an *in-medias-res* CBA of the 2013 Finnish Electricity Market Act (Sähkömarkkinalaki, 2013), enacted partially as a reaction to long, storm-induced electricity blackouts experienced after 2000 and particularly the long, widespread blackouts experienced in the 2011-2012 winter. The changing risk due to climate change is mentioned as one incentive to change the legislation. The Act imposes strict requirements on electricity distribution companies with regards to the duration of blackouts. Meeting the requirements entails investments amounting to approximately one billion euro, due to converting the infrastructure from overhead to underground cabling. As a benefit, the avoided cost from the blackouts for households and producers is quantified.

Uncertainty in the parameter values regarding the future development of climate change and other socio-economic factors affecting the CBA were derived from Monte-Carlo simulations. The results show that for urban areas, the net expected value is positive. However, in rural areas less strict requirements could have been economically more efficient, implying that flexible, less costly measures compared to underground cabling could have been used. The results indicate that the distributional impacts and correspondence between those who benefit and those who pay the costs should be considered in DRR and CCA policies that require large-scale investments.

The article shows that over-adaptation, leading to inefficient allocation of resources from an economic persective, effectively reducses the risk of extreme weather and climate change, but may not be accepted by the public as a viable way of reducing risk due to the high level of investment cost and the consequent significant rise in electricity prices.

Article IV: Innovations in weather services as a crucial building block for climate change adaptation in road transport

Article IV assessed the effects of improved weather service provision on the safety of road transport to improve CCA in the road transport sector. The objectives of the article are to: i) identify and describe the main trends and potential innovations in the provision and use of weather services in the road transport sector, ii) identify where in the weather service provision value chain these innovations would have an impact on the use of weather information before and during the trip and iii) analyse the expected magnitude of the value of these innovations. The analysis is based on a Weather Service Chain Analysis framework (Nurmi et al., 2013). The framework puts emphasis on the accuracy of the information, how it is disseminated, received and how the end user responds to the information; thereby, analysing the information decay throughout the value chain and resulting in an estimate of the fraction of the benefit potential realized. It provides an advantage over modelling approaches, such as the Cost-loss model (Katz and Murphy, 1997) that relies solely on forecast accuracy in assessing the benefits of information provided.

The study is based on 12 semi-structured expert interviews which aimed at identifying the trends and potential innovations in the provision and use of weather services and analyses the value of these innovations in the weather service provision value chain. Risk and uncertainty are key concepts. An uncertain changing climate will pose new risks to the road transport sector. Due to the uncertainty, robust methods are needed to reduce the risk in the changing conditions. Uncertainty is addressed through sensitivity analysis.

The largest gaps in the benefit realisation are related to access to up-to-date information and drivers' ability to respond. A large share of the drivers do not acquire weather information prior to their trips and base their opinions during the trip on the weather conditions mainly through their own observations. Therefore, development in the communication technology is a key enabler in this step. New ways to reach vehicle drivers, such as applications on mobile devices, services for satellite navigation devices and variable message systems are being developed.

5 CONCLUSIONS

The main research question of this thesis was to assess potential means to overcome the salient challenges in developing and applying DRM and CCA policies and measures that are designed to reduce the risks posed by extreme weather under uncertainty. This was achieved by identifying and analysing challenges related to DRM and CCA integration and their further integration into sectoral policies; exploring how governance, other socio-cultural structures, policies and their implementation can effectively reduce disaster risk and analysing the efficiency, effectiveness and legitimacy of DRM and CCA measures. It has contributed to the empirical analysis of integrated DRR and CCA policies and measures, and has analysed challenges related to their development and implementation. Theoretically, it advances the policy level development of DRR and CCA integration and provides a mathematical definition for over-adaptation to climate change.

Article I identifies that vulnerability reduction has not been the main focus of DRM and CCA policies in Zambia. Furthermore, even though the importance of integration is recognised by some actors, major challenges for integration in Zambia include siloed governance structures, lack of capacity in the relevant government organisations, coordination of multi-level governance and institutional lock-in. An important consideration should be to integrate long term CCA into existing DRM policies and measures and jointly integrate them in all relevant sectorial policies to effectively reduce the risk of disasters and climate change.

Article II shows that in Finland, the governance of DRM and CCA follow, to some extent, similar structures as in Zambia: DRM and CCA are the responsibility of different ministries, thereby, potentially causing inefficiencies in governance. However, the integration of DRM in sectorial policies is advanced, thus reducing potential inefficiencies. Furthermore, the Nordic Welfare State, its related governance structure and policy interventions, was shown to be effective in reducing societal and human vulnerabilities and in developing legislation that reduces disaster and climate change impacts.

The case in Article III serves as an example of the Finnish approach to DRM and CCA: it shows that a policy has the potential to substantially reduce the risk of extreme weather and climate change, but may not be accepted by the public anymore to the high level of investment cost and the consequent significant rise in electricity prices. The results indicate that distributional impacts and correspondence between those who benefit and those who pay the costs should be taken into account in DRM and CCA policies that require large-scale investments. Furthermore, in the case of over-investment, the population affected by a disaster may not accept DRR and CCA that are successful in terms of regulation and implementation. This applies when societal and individual preferences do not coincide.

Article IV shows how technological innovations, and the provision of improved weather information can decrease the impacts of extreme weather events on individuals. However, decision-making at individual level is still one of the defining factors behind the impacts; increasing information provision may not improve this but may require advances in technologies to overcome the challenge of human decision-making.

Despite the increasing number of studies focusing on the topic, no explicit definition has been provided in the literature for DRM and CCA policy integration. The lack of definition may not result in concrete inefficiencies or ineffectiveness in practice, but an explicit definition for integration aims at improving the systematic assessment of policy documents and other data in analysing DRM and CCA integration. At the practical level, the results from Zambia show how international discussion and local level experiences have increased the understanding of the linkages between DRR and CCA and initiated their integration. Although the benefits of integration are known among the key actors, the status quo is yet to be challenged, leading to parallel, inter-linked and potentially inefficient governance systems.

Even though integration, or mainstreaming DRM with the long-term CCA perspective in all relevant policy sectors—such as water management, agriculture, energy etc.—has gained increasing attention, it is still in its infancy. Integration in sectorial policies is at the core of efficient and effective DRM and CCA. Disasters and climate change do not operate in silos but affect most policy and economic sectors.

A prominent example of government intervention in Finland is the Electricity Market Act 2013, where the sectorial policy will effectively reduce the impacts of extreme weather; however, it suffered from lack of legitimacy among the public. This highlights the need to consider public opinion and potential and perceived negative effects on the public and emphasises the need for flexible and adaptive policies. For instance, Willingness-to-Pay studies prior to a major policy change could be warranted to avoid similar backlashes that took place in Finland. Effectiveness of the envisaged measures is a key criterion in designing DRM and CCA measures; however, the challenge for policy-makers is to design instruments that are accepted by the public. Even though most of the analyses in this thesis has focused on policies and large-scale investments for DRR and CCA developed mainly by public authorities, the decision-making level of an individual in DRR and CCA should not be forgotten. Individual level decision-making and actions become important before, during and after a severe weather or disaster situation. Even if the information provided has reached its full potential, people do not necessarily respond optimally, and human behaviour and decision-making are still the key factors in contributing to reducing the potential impacts from adverse weather conditions. Some responses to this challenge may arise from technology, particularly in road transport where major technological development is foreseen, but until the technological potential is reached, severe weather will lead to accidents and disasters due to lack of behavioural adaptation.

The main limitations of the thesis are related to the "snap shot" and case study nature of the studies. The articles could have been deepened, at least, in the following ways. Article I on the integration of DRR and CCA policies in Zambia is a snapshot of a moving target; a longitudinal, or a follow up, study on the policy landscape and measure implementation would be needed to conclude whether the situation is still valid, whether the recommendations given in the article were feasible and whether their potential implementation resulted in a more effective and efficient DRR and CCA. Even more interestingly, the definition for horizontal and vertical level integration of DRR and CCA policies should be analysed in various contexts, for instance in the European Union, to understand the current situation and potential challenges at a wider scale. Article II would have benefitted from collaboration with experts in political systems, such as the Nordic Welfare State, to further analyse the role of political systems and culture in DRR and CCA. Article III would have benefitted from a more thorough analysis of the willingness-to-pay for electricity blackouts, which may also change in the future; thereby, changing the results of the study. Furthermore, uncertainties regarding technological development in electricity production were omitted from the analysis. Article IV would have benefitted from collaboration with experts in behavioural science to improve our understanding of individual decision-making based on uncertain information, conflicting priorities of individuals and the lack of will to act in an effective way. These limitations can be turned into potential future research and call for inter-disciplinary approaches to address the above-mentioned shortcomings. However, noteworthy is that in the 'field' of this thesis, what matters in the end is action.

Lack of knowledge is not the most salient challenge regarding DRM and CCA. Research can contribute to increasing our knowledge only to some extend; the most important next steps are the actions taken by policy makers, practitioners and individuals in all fields of policy and practice to build the bridge between the inundated shores of DRM and CCA.

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